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ALUMINIUM ALLOY ROLLED SHEET FOR FORMING AND FINISHING AND A METHOD FOR THE MANUFACTURE THEREOF
[Seikei kakouyou aruminiumu goukin atsuenban oyobi sono seizou houhou]

Mamoru Matsuo, et al.

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INVENTORS	(72):	MATSUO, Mamoru; KOMATSUBARA, Toshio.
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SPECIFICATION /255*

1. Title of the Invention

ALUMINIUM ALLOY ROLLED SHEET FOR FORMING AND FINISHING AND A METHOD FOR THE MANUFACTURE THEREOF

2. Claims

(1) A rolled aluminum alloy sheet intended for forming, characterized by the facts of consisting of 0.4% to 2.5% of Si (% by weight, this also applies to the following) and 0.1% to 1.2% of Mg, with the remainder being Al and unavoidable impurities; and that the maximum size of intermetallic compound in the matrix is 5 μ or less.

(2) A rolled aluminum alloy sheet intended for forming, characterized by the facts of consisting of 0.4% to 2.5% of Si, and 0.1% to 1.2% of Mg, and also containing 1, 2, or more members of a group comprising 1.5% or less of Cu, 2.5% or less of Zn, 0.3% or less of Cr, 0.6% or less of Mn, and 0.3% or less of Zr, with the remainder being Al and unavoidable impurities; and that the maximum size of intermetallic compound in the matrix is 5 μ or less.

(3) A method for manufacturing a rolled aluminum alloy sheet, characterized by the fact that an aluminum alloy melt, consisting of 0.4% to 2.5% of Si and 0.1% to 1.2% of Mg, with the remainder being Al and unavoidable impurities, is continuously cast into a sheet with sheet thickness of 3 through 15 mm, this is then subjected to cold rolling, and then subjected to solution treatment/quenching.

* Numbers in the margin indicate pagination in the foreign text.

(4) A method for manufacturing a rolled aluminum alloy sheet, characterized by the fact that an aluminum alloy melt, consisting of 0.4% to 2.5% of Si, and 0.1% to 1.2% of Mg, and also containing 1, 2, or more members of a group comprising 1.5% or less of Cu, 2.5% or less of Zn, 0.3% or less of Cr, 0.6% or less of Mn, and 0.3% or less of Zr, with the remainder being Al and unavoidable impurities, is continuously cast into a sheet with a sheet thickness of 3 through 15 mm, this then is subjected to cold rolling, and then subjected to solution treatment/quenching.

3. Detailed Explanation

Industrial Field of Application

The present invention pertains to a rolled aluminum alloy sheet, and to a method for its manufacture, to be used in formed and finished products where high strength and superior forming and finishing properties, and particularly elongation, stretchability, and bending properties are required, such as for an automobile /256 body sheet, an air cleaner, or an oil tank, for example.

Prior Art

Conventionally, generally cold-rolled steel sheets have been widely used as sheets for automobiles for forming and finishing, such as body sheets for automobiles, but recently it has become increasingly desirable to use a rolled aluminum alloy sheet instead of the conventional cold-rolled steel sheet, in order to reduce the weight of an automobile's body and thus to improve fuel consumption, for example.

The materials that have conventionally been considered to be suitable as rolled aluminum alloy sheet to be offered for these applications are Al-Mg system 5052 0-tempered alloy or 5182 0-tempered alloy, or Al-Cu system 2036 T4-tempered alloy, as well as Al-Mg-Si system 6009 T4-tempered alloy or 6010 T4-tempered alloy, for example.

Problems to be solved by the invention

In comparison to cold-rolled steel sheet, the conventional rolled aluminum alloy sheet described above has inferior formability, and in particular elongation, bending properties, and stretchability are inferior.

More specifically, of the Al alloys mentioned above, the Al-Mg system alloys, such as 5052 alloy and 5182 alloy are relatively good in terms of formability, and corrosion resistance is also good, but these Al-Mg system O-tempered alloys have the defects of being susceptible to Luders' marks during the forming process, which give an unacceptable appearance, and of their strength being reduced by paint baking. A method of giving a slight processing warp by leveling, for example, is known as a technique for preventing the occurrence of Luders' marks in Al-Mg alloys, but is problematic in itself because formability is reduced, and the problem of strength being reduced after the paint baking process is not eliminated. Al-Cu-Mg system alloys, such as 2036 alloy, have superior strength and

Luders' marks do not form during forming and finishing, but they have the disadvantages of poor formability, and of strength being reduced after the paint baking process, as well as poor corrosion resistance. On the other hand, Al-Mg-Si system alloys such as 6010 alloy, have the advantage of superior strength, of Luders' marks not forming during forming and finishing, and of superior corrosion resistance and adequate strength after paint baking, but they have a single disadvantage of slightly inferior formability and finishing properties.

As mentioned above, among conventional Al alloys, the Al-Mg-Si systems, denominated with the 6000 series, have the maximum combination of superior properties. Therefore, if a solution could be found to the sole disadvantage of Al-Mg-Si system alloys, namely the slightly inferior formability and finishing properties, and in particular inferior elongation, bending properties, and stretchability, then it would be possible to offer an extremely excellent rolled aluminum alloy sheet as a material to be used in a body sheet for an automobile body, for example.

Given the background situation described above, the object of the invention is to improve the formability, and in particular elongation, bending properties, and stretchability, of Al-Mg-Si system alloys, and thereby to offer a rolled aluminum alloy sheet that has excellent properties for strength, formability, absence of Luders' marks, corrosion resistance, and strength after the paint baking process.

Means to Solve the Problem

As a result of conducting a series of experiments and investigations of techniques for improving the formability, and in particular elongation, bending properties, and stretchability of Al-Mg-Si system rolled alloy sheet, the inventors discovered that keeping the maximum size of intermetallic compounds in the final rolled sheet to 5 μm or less was effective for improving elongation, bending properties, and stretchability. The inventors further discovered that the direct continuous casting to a plate with thickness of 3-15 mm is an effective means of keeping the maximum size of intermetallic compounds in the final rolled sheet to 5 μm or less, thereby arriving at the present invention.

Specifically, the first invention of the present application is a rolled aluminum alloy sheet, characterized by the facts of consisting of 0.4% to 2.5% of Si and 0.1% to 1.2% of Mg, with the remainder being Al and unavoidable impurities; and that the maximum size of intermetallic compound in the matrix is 5 μ or less.

The rolled aluminum alloy sheet of the second invention is characterized by the fact of consisting of 0.4% to 2.5% of Si, and 0.1% to 1.2% of Mg, and also containing 1, 2, or more members of a group comprising 1.5% or less of Cu, 2.5% or less of Zn, 0.3% or less of Cr, 0.6% or less of Mn, and 0.3% or less of Zr, with the remainder being Al and unavoidable impurities; and that the maximum size of intermetallic compound in the matrix is 5 μ or less. /257

The method for manufacturing a rolled aluminum alloy sheet of the third invention is characterized by the fact that an aluminum alloy melt, consisting of 0.4% to 2.5% of Si and 0.1% to 1.2% of Mg, with the remainder being Al and unavoidable impurities, is continuously cast into a sheet with sheet thickness of 3 through 15 mm, this then is subjected to cold rolling, and then subjected to solution treatment/quenching.

The method for manufacturing a rolled aluminum alloy sheet of the fourth invention is characterized by the fact that an aluminum alloy melt, consisting of 0.4% to 2.5% of Si, and 0.1% to 1.2% of Mg, and also containing 1, 2, or more members of a group comprising 1.5% or less of Cu, 2.5% or less of Zn, 0.3% or less of Cr, 0.6% or less of Mn, and 0.3% or less of Zr, with the remainder being Al and unavoidable impurities, is continuously cast into a sheet with sheet thickness of 3 through 15 mm, this then is subjected to cold rolling, and then subjected to solution treatment/quenching.

Operation

First the reasons for limiting the basic alloy ingredients of the invention are explained.

Mg:

Mg is a required alloy ingredient for the invented system for an aluminum alloy, being an element that confers strength and formability. If Mg is less than 0.1%, the strength will be insufficient and the obtained sheet will be unsuitable as an automobile body sheet, for example. Conversely, if Mg exceeds 1.2%, the ductility and formability will be reduced. Thus the range has been limited to 0.1% through 1.2%.

Si:

Si is a required alloy ingredient for the invented system for an aluminum alloy, being an element that confers strength and formability. If Si is less than 0.4%, the strength will be insufficient. Conversely, if Si exceeds 2.5%, the melt fluidity will be reduced and continuous casting will be difficult. Thus the range has been limited to 0.4% through 2.5%.

The second invention of the present application provides for the addition of 1, 2, or more members selected from a group comprising Cu, Zn, Mn, Cr, and Zr. The reasons for this addition and the reasons for the limitations are as follows.

Cu and Zn:

The strength may be further improved by the addition of these elements. If Cu exceeds 1.5% or Zn exceeds 2.5%, corrosion resistance will be reduced, and continuous casting will be difficult. Formability will also be reduced if Cu exceeds 1.5%. Accordingly, the upper limit for Cu is 1.5% and the upper limit for Zn is 2.5%. There are no particular constraints on the lower limits, but if Cu is less than 0.05% and Zn less than 0.1%, the effect of adding Cu or Zn will be insufficient. Therefore it is desirable to add 0.05% or more of

Cu, or 0.1% or more of Zn.

Cr, Mn, Zr:

These elements are all elements that contribute to improving strength and also to uniformity of texture by making recrystallized grains more delicate. If Mn exceeds 0.6%, formability will be reduced. If either Cr or Zr exceeds 0.3%, coarse intermetallic compounds will be produced. Accordingly, the upper limits are set at 0.6% for Mn and 0.3% for Cr and Zr. There are no particular lower limits on Mn, Cr, and Zr, but the effect of adding these elements is not obtained if Mn is less than 0.05%, or if Cr or Zr is less than 0.03%. Accordingly, it is desirable to add 0.05% or more of Mn and 0.03% or more of Cr or Zr.

In addition to the elements mentioned above, normally Fe is contained in an aluminum alloy as an unavoidable impurity. Fe is not a particularly important element in the present invention, but if the amount exceeds 0.5% the quantity that crystallizes out will increase and formability will be poor. Therefore it is desirable for the amount of Fe to be 0.5% or less.

In addition to the elements mentioned above, it is possible to add Ti or Ti and B for the purpose of finer crystal granularity in the ingot. Nevertheless, it is desirable for Ti to be less than 0.15%, in order to prevent primary $TiAl_3$ grains from crystallizing out. It is also preferable for the content of B to be less than 0.01% in order to prevent the formation of TiB_2 grains.

It is not only important for the rolled aluminum alloy sheet of the first invention and the second invention to have the ingredient composition described above, but also for the maximum size of the intermetallic compounds in the rolled surface of the final rolled sheet to be 5 µm or less. The improvement of formability, and in particular elongation, bending properties, and stretchability, is possible by restricting the maximum size of intermetallic compounds to 5 µm or less in this way. If the maximum size of intermetallic compounds exceeds 5 µm, the effect described above will not be obtained. A suitable way of limiting the size of intermetallic compounds in the final rolled sheet in this way is, as described below, at the casting stage, to conduct direct casting into a sheet 3 – 15 mm thick by continuous casting, and to increase the rate of solidification. /258

Next, methods for manufacturing such a rolled aluminum alloy sheet, namely, the third invention and the fourth invention, are described below.

In this manufacturing method, first, it is important that an aluminum alloy melt having the ingredient composition described above be cast, and that this be continuous casting into a sheet that is 3–15 mm thick. As a specific method, it is desirable to apply a method in which alloy melt is supplied continuously to a pair of rollers that are cooled from within, while at the same time the rollers are made to revolve continuously, and a sheet solidified to a thickness of 3–15 mm is continuously drawn off. The direct, continuous casting of a thin sheet in this way makes it possible to obtain a high solidification rate.

As mentioned above, a high solidification rate during the casting process is necessary for keeping the maximum size of intermetallic compounds at the rolled surface of the final rolled plate to 5 μm or less. For an alloy with the present system, it has been experimentally demonstrated by the inventors that the dendrite arm interval must be an average of 10 μm or less during casting, and that the cooling rate must be 100°C/sec or greater, and these conditions can be satisfied by direct continuous casting into a sheet 3 through 15 mm thick. The casting process itself becomes problematic if the casting sheet thickness is less than 3 mm. Conversely, if the sheet is thicker than 15 mm, it will be difficult to keep the average dendrite arm interval at 10 μm or below, and thus it is be difficult to control the maximum size of intermetallic compound in the final rolled sheet to 5 μm or less, in which case the intended formability, and in particular elongation, bending properties, and stretchability, will not be obtained.

As the occasion may require, it is possible to subject a sheet that has been continuously cast as described above to a cold rolling treatment in order to achieve a desired thickness, after a homogenization treatment has been conducted at 450°C – 600°C. The rolling rate for this cold rolling treatment may be set according to the thickness of the cast sheet and the desired end product thickness, but ordinarily a rate of about 20% is preferable.

After a cold rolling process, a solid annealing treatment/quenching process is conducted. The solid annealing treatment and quenching process may be conducted according to methods known to the art. Specifically, a solid annealing treatment may be conducted by heating an Al-Mg-Si system alloy to an ordinary solid annealing treatment temperature (on the order of 470°C - 600°C). Quenching may be conducted by either forced air, mist quenching, or water quenching, for example, as long as the cooling rate is approximately 5°C/sec or greater. It is effective for the heating up to the solid annealing temperature to be performed rapidly for the purpose of finer crystalline granules, thus the use of a continuous heating quenching furnace or salt bath furnace is preferred.

Because the alloy of the invented system is a heat treatment-type aluminum alloy, its strength is gradually increased when it is allowed to stand at room temperature after quenching, and this strength becomes saturated after 3-7 days.

Working Examples

The alloys shown as Alloy Nos. 1 through 6 on Table 1 were continuously cast into sheets 6 mm thick, by a continuous casting method in which an alloy melt was continuously fed in between a pair of revolving, cooled rollers. The obtained continuously cast sheets were cold rolled to a thickness of 1 mm.

As a comparison method, alloys identical to Alloy Nos. 1 through 6 of Table 1 were cast into slabs 400 mm thick by DC casting, these were subjected to a homogenization treatment at 530–560°C for 10 hours, then hot-rolled to 6 mm beginning with hot rolling at 500°C. The hot-rolled sheet was then cold rolled into a 1 mm sheet

Each of the cold-rolled sheets of Alloy Nos. 1 through 6, obtained as mentioned above, was subjected to solution annealing and quenching under the conditions listed in Table 2. Alloys that had identical compositions were subjected to solution annealing and quenching under identical conditions, whether they were sheets that had been continuously cast and then cold rolled (invented material) or obtained by DC casting and cold rolling (comparative material).

The data shown in Table 3 are the results of investigating the maximum sizes of intermetallic compounds occurring on the rolled surfaces of plates of either the invented material (obtained by continuous casting) or of comparative material (obtained by DC casting), after the heat treatment described above had been /259
applied.

After the heat treatment described above had been conducted, samples were allowed to stand for at least 1 week, and subjected to room temperature aging. Then the samples were tested for mechanical strength (tensile strength, 0.2% proof strength), elongation, Erichsen value, and minimum bending radius at 180° bending. These findings are shown in Table 3, together with the results of proof strength tests performed after samples had been subjected to heating at 200°C x 30 minutes, to simulate the paint baking process after room temperature aging.

Table 1

Alloy No.	Alloy Ingredients (wt%)						
	Si	Mg	Cu	Fe	Mn	Zn	Cr	Zr
1	1.63	0.72	0.32	0.24	Tr	Tr	0.15	Tr
2	0.86	0.84	0.29	0.21	0.24	Tr	Tr	Tr
3	1.23	0.22	0.71	0.16	0.18	Tr	Tr	Tr
4	0.73	0.63	Tr	0.23	Tr	0.32	Tr	0.12
5	0.88	0.43	Tr	0.18	Tr	Tr	Tr	Tr
6	1.73	0.53	Tr	0.22	Tr	Tr	Tr	Tr

Table 2: Solution annealing and quenching conditions

Alloy No.	Solution annealing	Quenching	Means applied
1	530°C x 3 min	Forced air (30°C/sec)	Continuous heating/quenching (heating rate 30°C/sec)
2	530°C x 30 min	Water quenching (>2000°C/sec)	Air heating furnace (heating rate 0.2°C/sec)
3	540°C x 3 min	Forced air (30°C/sec)	Continuous heating/quenching (heating rate 30°C/sec)
4	530°C x 1 min	Water quenching (>2000°C/sec)	Salt bath (heating rate > 2000°C/sec)
5	530°C x 1 min	Forced air (30°C/sec)	Continuous heating/quenching (heating rate 30°C/sec)
6	540°C x 3 min	Forced air (30°C/sec)	Continuous heating/quenching (heating rate 30°C/sec)

Table 3

Alloy No.	Class	Max. size of intermetallic compounds	Tensile strength (Kg/mm^2)	0.2% Proof strength	Elonation (%)	Er value (mm)	Minimum bending radius (mm)	Proof strength after heating to 200°C x 30 min (kg/mm^2)
1	Invented material	3.1 μm	30.3	15.8	32	10.1	0.2	28.1
	Comparative material	13.5 μm	29.2	15.1	30	9.5	0.5	28.5
2	Invented material	3.4 μm	31.0	16.2	30	9.6	0.3	27.3
	Comparative material	15.1 μm	31.3	16.0	27	9.0	0.7	27.1
3	Invented material	2.9 μm	25.3	12.9	33	10.3	0.1	19.3
	Comparative material	12.8 μm	25.6	12.8	30	9.6	0.5	19.1
4	Invented material	3.3 μm	27.5	14.3	32	10.0	0.2	25.8
	Comparative material	15.2 μm	27.7	14.5	29	9.5	0.5	25.5
5	Invented material	3.0 μm	28.6	14.0	32	10.3	0.2	27.9
	Comparative material	14.8 μm	28.0	13.9	30	9.7	0.5	27.8
6	Invented material	3.5 μm	30.1	15.2	32	10.1	0.2	28.3
	Comparative material	14.5 μm	29.4	14.9	29	9.6	0.6	28.2

As is clearly shown in Table 3, in cases of the invented material, obtained by direct casting into 6 mm sheets by continuous casting, the maximum size of intermetallic compound in the final sheet was 5 μm or less in every case; this is an improvement of formability in comparison to the comparative materials obtained by casting 400 mm thick slabs by DC casting (in these cases, the maximum size of intermetallic compound in the final sheets was 12 μm - 16 μm).

In all cases proof strength was improved for heating to 200°C x 30 min, stipulated for paint baking, which demonstrates the potential for bake hardening. In no case were Luders' marks observed to occur during the forming and finishing processes. Accordingly, it is demonstrated that the invented material has not lost the advantage of conventional Al-Mg-Si system alloy in the non-occurrence of Luders' marks, nor has it lost the advantage of being suitable for bake hardening.

Effect of the invention

As has been clarified by the working examples described above, the invented Al-Mg-Si system rolled alloy sheet for forming and finishing has superior formability, and in particular elongation, bending properties, and stretchability, in comparison to a conventional Al-Mg-Si system alloy (6000 series alloy), such as 6010 alloys, for example. More specifically, the invented aluminum alloy sheet has superior strength and corrosion resistance, which are advantages of conventional 6000 series alloys, and also has the properties of Luders' marks not occurring, and high temperature [sic] after a paint baking operation; in addition, the sole disadvantage of a conventional 6000 series alloy, which is the slightly inferior formability, is eliminated. The invented aluminum alloy sheet is thus furnished, both with the aforementioned various advantages from the prior art, and superior formability, and in particular elongation, bending properties, and stretchability.

Accordingly, the invented aluminum alloy rolled sheet is suitable for use in applications for automobile body sheets, where the aforementioned properties are required. It is obvious that it will also exhibit superior properties when it is used in other applications for formed and finished products, such as wheels and oil tanks, air cleaners and other automobile parts, as well as various caps and blinds, aluminum cans, household utensils, instrument covers, and chassis for electrical appliances, for example.